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Moisture Sensitivity of Crumb Rubber Modified Modifier Warm Mix Asphalt Additive for Two Different Compaction Temperatures

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Abstract. Crumb rubber obtained from scrap tires has been incorporated with asphalt binder to improve the performance of asphalt mixtures in the past decades. Pavements containing crumb-rubber modified (CRM) binders present one major drawback: larger amounts of greenhouse gas emissions are produced as there is rise in the energy consumption at the asphalt plant due to the higher viscosity of these type of binders compared with a conventional mixture. The objective of this paper is to calculate the optimum bitumen content for each percentage and evaluate the moisture sensitivity of crumb rubber modified asphalt at two different compacting temperatures. In this study, crumb rubber modified percentages was 0%, 5%, 10% and 15% from the binder weight, with adding 1.5% warm mix asphalt additive (Sasobit) and crush granite aggregate of 9.5mm Nominal maximum size was used after assessing its properties. Ordinary Portland Cement (OPC) used by 2% from fine aggregate. The wet method was using to mix the CRM with bitumen, the CRM conducted at 177°C for 30 min with 700rpm and Sasobit conducted at 120°C for 10 min with 1000rpm. As a result, from this study the optimum bitumen content (OBC) was increased with increased crumb rubber content. For performance test, it was conducted using the AASHTO T283 (2007): Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage. The result was as expected and it was within the specification of the test, the result show that the moisture damage increased with increased the crumb rubber content but it is not exceeding the limit of specification 80% for indirect tension strength ratio (ITSR). For the temperature was with lowering the temperature the moisture damage increased.

1. Introduction

Using recyclable materials in road construction is one of the best options that related industries have obtained extensive experience about the use of by-products in asphalt. Examples of wastes that have been used in asphalt mixtures, including glass baking furnace dross, ash obtained from incineration of municipal waste, crushed brick, plastic, rubber obtained from waste tires, waste glass and waste rubber powder. However, successful use of these products is depending on a full investigation of the sources and their characteristics and usually is done at a low level. Waste crumb rubber utilization as a modifier in asphalt has been considerable over the recent four decades, researches Carried out in the manufacture



of rubber asphalt pavement indicated reduction of pavement thickness, increase of pavement life, becoming less refractive, less reflective rate, less traffic noise, reduction of maintenance costs, reduction of pollution and improve environmental issues [12].

Generally, crumb rubber is manufactured from automotive and truck scrap tires. From an engineering point of view, crumb rubber has a number of special thermo-mechanical and chemical physical properties. The size of the rubber particles is graded and can be found in many shapes and sizes. The finest one can be as small as about 0.2 mm and below. The gradation commonly used in rubberized asphalt pavement is between about 2.0 mm to 0.5 mm. Crumb rubber is light in weight, durable and from safety aspect crumb rubber can be categorized as a non-toxic and inert material [11]. Annually, about one billion, equivalent 9 million tons' waste tires are produced in the world, due to the shortage of landfill space and environmental issues, recycling old tires seem necessary [6]. A number of methods have been applied in attempt to find more effective ways to recycle the scrap tires, one of the methods among them is to use the crumb rubber in modification of asphalt binders. It is reported that the asphalt industry can absorb up to 40% of scrap tire [5]. [15] study on the effect of crumb rubber modifier on the sensitivity of high temperature of the surface mixture and evaluated the effect of different sizes of crumb rubber on high temperature sensitivity of three type of surface mixture.

The evaluation was conducted in two parts: first, the properties of the modified and unmodified bitumen in a wide range of test temperatures and second, aging conditions have been compared. The results showed that the bitumen modified with crumb rubber have better resistance against moisture sensitivity [14]. The moisture sensitivity evaluation using Superpave method to determine the optimal conditions for the use of tire rubber in asphalt concrete, granulated crumb rubber was considered, fusion temperature, aggregate gradation, and the amount of crumb rubber, density, temperature, the amount of bitumen and fusion time as experimental variables. In their study, the method of dry mixing crumb rubber in asphalt concrete was used [13]. Moisture damage can be defined as the loss of strength and durability in asphalt mixtures due to the effects of moisture. Moisture damage can occur because of a loss of bond between the asphalt cement and mastic (asphalt cement plus the mineral filler-74 μ m and smaller aggregate) and the fine and coarse aggregate. Moisture damage also can happen because moisture permeates and weakens the mastic, making it more susceptible to moisture during cyclic loading.

The distress problems in asphalt pavement include stripping, potholes, rutting and others distress effect is caused from the presence of water at asphalt pavement. The presence of water can affect the durability and workability of pavement layer. Moisture can cause adhesion failure, hence stripping of asphalt binder from aggregates [7].

In addition, the weathering condition also can affect the moisture sensitivity to the pavements layer such as pavements are subjects to moisture during rainy season. Water can infiltrate the pavement from the surface via cracks in the pavement surface, via the interconnectivity of the air-voids system or cracks, from the bottom due to an increase in the ground water level, or from the sides. According to [18]. It can be summarized the factors at the Table 1 below.

Table 1. The factors influencing moisture damage.

Mix design	•	Binder and aggregate chemistry.
	•	Binder content.
	•	Air voids.
	•	Additives.
Production	•	Percent of the aggregate coating and the quality of passing the no. 200 sieve.
	•	Temperature at plant.
	•	Excess aggregate moisture content.
Construction	•	Compaction-high in place air voids.
	•	Permeability-high values.
	•	Mix segregation.

2. Methodology

2.1 Materials preparation

In this study, bitumen binder 80/100 penetration grade was used. In this study crush granite aggregate of 9.5mm Nominal maximum size provided by the UTHM laboratory was used after assessing its properties, and found to have met the requirement of the relevant specifications. Crumb rubber powder of 20 mesh sizes (passing 0.15mm) used. The Crumb rubber was obtained from a Malaysian Supplier (Miroad Rubber Industries Sdn Bhd) the crumb rubber modifier (CRM) was produced by mechanical shredding and then grinded at ambient temperature. The Sasobit was fixed addition by 1.5% from the binder weight and Ordinary Portland Cement (OPC) used by 2% from fine aggregate. According to [9] the percentage of OPC must be not exceeds 2%.

2.2 Experimental work

The Modified binders used in this study were prepared by blending the Original 80/100 bitumen with Sasobit and Crumb Rubber, this process is known as ‘Wet Process’ because the additive(s) were added to the bitumen. The unmodified penetration grade bitumen 80/100 (Original or virginal ‘A’) was blended with the additives to produce three additional binders; X, Y and Z depending on the binder composition. Table 2, shows the Matrix of binder identity and composition.

Table 2. Binder Identity and Composition Matrix.

Binder Identity	Constituent Materials (%)		
	80/100 Bitumen	Sasobit® %	Crumb Rubber %
A	100	-	-
X	100	1.5	5
Y	100	1.5	10
Z	100	1.5	15

Crumb Rubber Modifier was added at 5%, 10% and 15% by weight of the base binder to produce crumb rubber modified binders; CRM blending was conducted at 177°C and mixed continuously for 30

min, using mechanical mixer at 700rpm [17]. The 1.5% Sasobit by weight of the base binder which is within the recommended dosage of 0.8 to 3% [8]. The Sasobit was added at 120°C and was blended the same way the CRM was blended only that the mixing speed and time was 1000 rpm and 10 minutes respectively. The prepared binders were used immediately after modification, to avoid segregation upon storage due to its poor storage stability. The steps followed to prepare the samples are: the blended aggregate was placed in a bowl and weigh to the required weight (1200 g of aggregate was used for batching) and mixed thoroughly and then the aggregate sample together with the required asphalt binder were placed for conditioning in the oven at mix temperature for 2 hours and then both the aggregate and the binder were removed and mix using the mechanical mixer until the specimen were thoroughly coated. The mixture (rice) was then put back to the bowl and placed in an oven for short-term aging for 2 hours at the temperature equals the required mixtures compaction temperature then the mixture was then compacted using Superpave Gyratory Compactor. The optimum Bitumen content was determined according to Superpave mix design method, after establishing the aggregate blend. Four trial asphalt content of 5.5%, 6.0%, 6.5% and 7.0% was used, traffic level selected was for 3 to < 30 ESALS with compaction levels of 8, 100 and 160 for $N_{initial}$, N_{design} and N_{max} respectively [1], [2]. The plot of air void versus binder content was plotted, and the binder content that gives 4.0% air void at N_{design} was determined as the optimum binder content. Before the conduct of the test, the mix was short-term aged in an oven for 2 hours at 145°C and 135°C for mixing and 135°C and 125°C for compaction temperatures respectively. The procedure adopted was based on [1], [2]. Each percentage need 6 samples so for 4 percentages and two mixing temperatures, it prepared 48 samples to conduct the test and another 75 samples for OBC.

3. Result and discussion

3.1 Optimum binder content result

The OBC was conducted for all 4 percentages (0%, 5%, 10%, 15%) and the Tables 3, 4, 5, 6 shown that results.

Table 3. Volumetric properties for original at the N_{design} (100gyration).

Tial	Binder Content (%)	V _a (%)	VMA (%)	VFA (%)
1	5.5	5.3	19.2	64.04
2	6.0	3.9	18.2	74.93
3	6.5	3.3	18.3	80.77
4	7.0	3.2	19.3	81.97
OBC at	6.0	4	18.2	74.93
Superpave® Criteria		4%	min 15%	65 -75

The Table 3 show that the optimum binder content at 4 % air voids was 6%. The optimum bitumen content was high related to use small gradation of aggregate 9.5mm (NMAS) gradation. All thus, if the nominal maximum aggregate size low the binder content will be high [4].

Table 4. Volumetric properties for 5% CRM at the N_{design} (100gyration).

Trial	Binder Content (%)	V_a (%)	VMA (%)	VFA (%)
1	5.5	5.5	19.6	62.67
2	6.0	4.4	18.6	72.49
3	6.5	3.6	18.6	77.41
4	7.0	2.9	19	85.66
OBC at	6.25	4	18.6	74.95
Superpave® Criteria		4%	min 15%	65 -75

The Table 4 present the optimum binder content on modified binder with 5% CRM and at 4% air voids the binder content was 6.25%. There are two reason of high binder content which are: nominal maximum aggregate (size 9.5mm) and the crumb rubber modified need more binder content because the particles of rubber absorb the bitumen that needed to make strong bond between the aggregate and the bitumen.

Table 5. Volumetric properties for 10% CRM at the N_{design} (100gyration).

Trial	Binder Content (%)	V_a (%)	VMA (%)	VFA (%)
1	5.5	5.3	18.7	65.72
2	6.0	4.6	18.2	74.02
3	6.5	3.9	19.2	75.19
4	7.0	2.9	18.7	84.97
OBC at	6.5	4	19.2	75.19
Superpave® Criteria		4%	min 15%	65 -75

Table 6. Volumetric properties for 15% CRM at the N_{design} (100gyration)

Trial	Binder Content (%)	V_a (%)	VMA (%)	VFA (%)
1	5.5	5.4	19.3	64.25
2	6.0	5.1	18.9	71.17
3	6.5	4.4	19.7	73.73
4	7.0	3.8	19.6	80.91
OBC at	6.8	4	19.5	75.01
Superpave® Criteria		4%	min 15%	65 -75

The Table 5 shows increased at binder content because increased the percentage of CRM at binder. As a result, the optimum binder content at 4% air voids for 10% CRM is 6.5%. The Table 6 present the optimum binder content at the highest percentages of CRM at this study which is 15% of CRM and the outcome was at 4% air voids the modified binder content is 6.8%. The high amount of bitumen 6.8% in the mixture because the particulars of CRM absorb some of the bitumen. Second, the CRM particulars

have surface area and the surface area will cover by the bitumen. The size of the aggregate gradation is small that's mean the surface area of the aggregate will be wider and it will lead to increase the amount of the bitumen in the mixture. As a result, with raise the content of CRM, the bitumen amount will increase.

3.2 The performance test

The moisture sensitivity test was conducted accordance to AASHTO T283: Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage. In order to:

I - Assess the effect of Crumb Rubber Modifier CRM on moisture sensitivity of warm mix asphalt mixtures incorporating Sasobit.

II - Assess the effect of compaction temperature on moisture sensitivity of warm mix asphalt mixtures modified with CRM.

3.2.1 Effect of CRM on moisture sensitivity on warm mix asphalt. The indirect tensile strength ratio (ITSR) test was performed to evaluate the resistance of water sensitivity of asphalt mixtures incorporating Sasobit and anti-stripping agent. Figure 1 depicts the tensile strength ratio whit different percentages of CRM (original, 5%, 10%, 15%). The original binder giving 88.4% tensile strength ratio this is high compare to the modified binder. Meanwhile the tensile strength ratio with 5% of CRM is 87.2% that show slight decreased compare to unmodified binder. However, the value of tensile strength ratio for 10% and 15% are 83.1%, 80.8 respectively and this mean with rising the percentage of CRM the tensile ratio decreased.

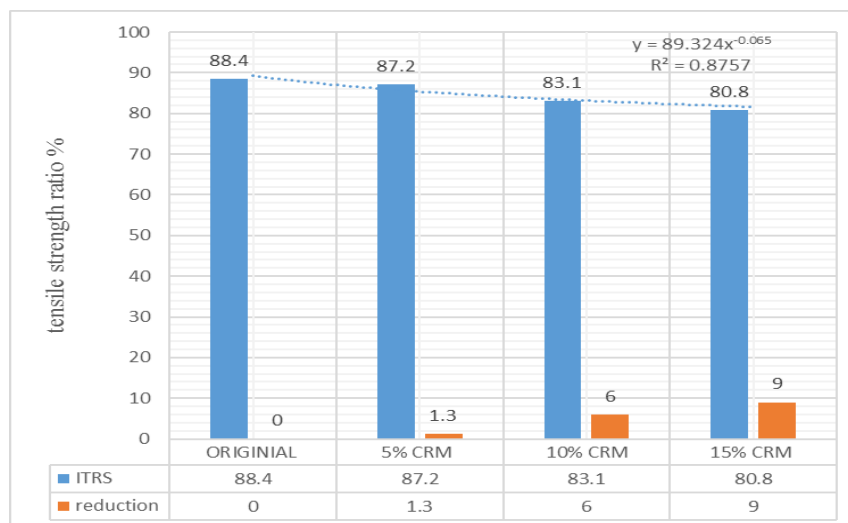


Figure 1. Effect of CRM on tensile strength ratio in WMA.

There is reduction at ITSR result between the original mixture and the modified mixtures, and the drooping happened with add the CRM to the binder. The run-down was 1.3% between the original and the 5% of CRM and the reduction between the original mixture and 10% of CRM was 6%. The reduction at 15% of CRM was the highest reduction and it was 9%. According to [10], the tensile strength ratio become lower with increased the percentages of CRM because of the compaction suffered by the mix with elastic behavior lead to air voids. The CRM generates more air voids in the mix and causes poorer cohesion and this led to less satisfactory response to moisture action. According to [16], the large binder surface area leads to oxidative effect of air and damaging effect of water resulting increasing interfacial moisture content, command to the de-bonding of bitumen films from aggregate surface, which greater affinity of the aggregate from water than from bitumen. Thus, the effects of CRM at binder which are

make it increasing that lead to lager binder surface area at mixture. The correlation coefficients R^2 was 0.8757, the result of R^2 was good according to the fit statistical parameters.

3.2.2 Effect the compaction temperature on CRM warm mix asphalt in moistures Sensitivity. The indirect tensile strength ratio (ITSR) test conducted at two different compaction temperatures 135°C and 125°C, 135°C for mixing temperature. From figure 2 the result of original binder at 135°C higher than original binder at 125°C. the result decreased from 88.4% to 86%. For the modified mixture was the same result which is when the temperature of compacting decreased the tensile ratio is lower. The reduction in compaction temperature adversely affects the mixture susceptibility to water damage due to incomplete drying and entrapment of moisture in the aggregate during heating and mixing at lower temperature.

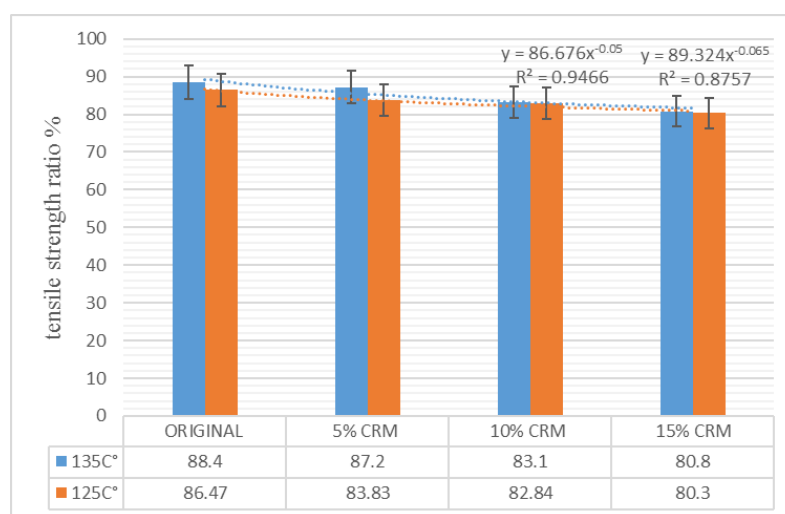


Figure 2. Effect of CRM on tensile strength ratio at different compaction temperature.

The specimens compacted at low temperature are more susceptible to water damage. However, due to high air voids, the water infiltration into the PA mixture and wash away of mastic through the connected macro pores, loss of cohesion and the failure of the asphalt bond with aggregate happened resulting in low ITSR values. For the modified mixture 5%, 10% and 15% at 135°C compacted temperature the result was 87.2%, 83.1% and 80.8%. Meanwhile for modified mixture 5%, 10% and 15% at 125°C compacted temperature the result was 83.83%, 82.84% and 80.3%. The R^2 for 135°C was 0.8757 this good quality of correlation. Meanwhile the R^2 for 125°C was 0.9466 that excellent quality of correlation.

4. Conclusion

The crumb rubber modified shows lower tensile strength ratio compared to the original mixture, for the mixtures compacted at 125°C and 135°C. Also, the tensile strength ratio of the WMA mixtures decreases with reduce the test temperature and decreases with higher CRM content. The (ITSR) of the WMA mixtures generally decreases with reduce in compaction temperature for the corresponding mixture. Over the entire range of compaction temperature considered, the (ITSR) are higher when tested at higher temperature. The binders with CRM better/higher moisture resistance but for mixture were found the mixture with CRM lower moisture resistance from T-283 test. As a result, the modified binder with high OBC when interact with the aggregate the area of surface will increase and one of the reason cause for moisture damage is the area of surface for aggregate. This reason leads to infiltration the water inside the mixture and break the bonding between the aggregate and bitumen. Even that the result of (ITSR)

was decreased by adding CRM, the result was over the limit of (ITSR) specification 80% and that good result according to specification of the moisture damage test.

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